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Understanding Innovation in European Mountain Product Value Chains: Empirical Typology, Patterns of Co-occurrence, and Policy Implications

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Mountains, encompassing 36% of Europe's territory and home to one sixth of its population, are rich in natural, cultural, human, and economic resources. Despite these assets, mountain communities face challenges such as depopulation, limited infrastructure, urbanization pressures, tourism impacts, and climate change. Yet, they also host resilient economic activities that enhance the value of local resources through specialized value chains. This study examined innovation within a dataset of over 455 European mountain product value chains (MPVCs), identifying innovative characteristics in 275 MPVCs. We empirically identified 12 innovation attributes and their co-occurrence patterns. Further analysis explored how these attributes relate to regional innovation measurements. Equipping stakeholders and policymakers with insights into how MPVC innovations emerge across mountain regions, cluster, and interact with territorial factors, this research serves to inform supportive and context-sensitive policy and strategic planning.

Keywords: *innovation; mountain economies; regional development; innovation drivers; innovation typology; social–ecological innovation; mountain value chain; mountain products.*

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Introduction

Mountain regions in Europe face intertwined challenges, described as "polytraps," which encompass a combination of economic, environmental, social, and institutional constraints (Sarkki et al 2025). These challenges are compounded by rapid climate change and structural disadvantages that make sustainable development and resilience particularly difficult to achieve. Mountainous areas are especially vulnerable, as they are high-risk zones for natural disasters, popular tourism destinations, and reservoirs of cultural traditions, concurrently (Schneiderbauer et al 2023).

Simultaneously, demographic and development trajectories are becoming increasingly diverse across regions, where some are struggling with decreasing gross domestic product (GDP) and demographic shrinkage while others are experiencing return migration, lifestyle immigration, or urban spillover (Gløersen et al 2012; Gløersen, Price, et al 2016; Iammarino et al 2019; Steinführer and Haartsen 2022). This heterogeneity challenges simplistic narratives of decline and underscores the need for nuanced, place-sensitive policy responses (Gløersen, Mader, and Ruoss 2016). However, regional and European Union (EU) policies often impose contradictory expectations on mountain communities—demanding self-reliance, competitiveness, and innovation despite their structural disadvantages—while omitting to mention or support specificities in innovation for mountain areas in cohesion policy tools (Gløersen et al 2012; EC 2024). Addressing these contradictions requires broadening the concept of innovation to include socially embedded, context-responsive forms of adaptation, rather than focusing solely on generic technological or productivity-driven approaches.

The conceptualization of innovation as technological progress tied to economic development and a key factor for increasing GDP traces back to Schumpeter's Theory of Economic Development (Schumpeter 1934). Unsurprisingly, countries with higher GDP rank higher on innovation scores (Gürler 2022), as shown on the European Innovation Scoreboard. The European scoring details on

the Regional Innovation Scoreboard (RIS) offer a localized perspective across 4 categories: framework conditions, investments, innovation activities, and impacts (EC 2023a). Policy measures define framework conditions and investments, but innovation activities and impacts depend heavily on local actors. The difficulty of distinguishing among drivers, innovations, and impacts complicates policy support (Coca et al 2023). The EU and national governments have long included innovation in development strategies for rural areas (Gløersen et al 2012; EC 2024) and invest via the cohesion policy and the common agricultural policy (CAP) in enabling frameworks, such as the European Innovation Partnership (EIP) and regional development programs (RDPs), including bottom-up local initiatives (Liaison Entre Actions de Développement de l'Économie Rurale [LEADER]/ community-led local development [CLLD]), smart villages, spending for climate and the environment, and supportive financial instruments (EC n.d.). These measures aim to support a "green, smart, and inclusive transition" in rural areas (Neumeier and Pollermann 2014), as can clearly be seen in the priority targets for RDPs, or in the long-term vision for rural areas (EC n.d.; EU n.d.). Still, the empirical evidence on how such programs support—and could improve—the operationalization of innovative practices for such a transition toward green, smart, and inclusive rural areas remains weak.

Scholars in economic geography and regional science have emphasized that innovation is not universally replicable, but path dependent and shaped by historical, institutional, and socioeconomic factors (Crevoisier and Jeannerat 2009; Crevoisier 2014; Capello and Nijkamp 2019). In structurally constrained contexts, technology-driven models may be unfeasible, and locally grounded solutions—such as adaptive reuse and community learning—become key factors (Moulaert et al 2005; Bosworth et al 2020). Mountains are contexts with high constraints that are likely to catalyze innovations by necessity in a bottom-up, loosely organized way (Mathews 2013; Bock 2016; Acar et al 2019).

Still, many publications concerning mountain areas limit innovation to new products, services, or management approaches (Hansen et al 2007; Wilkes-Allemann et al 2020). Marescotti et al (2021) for example examined smart farming and technology adoption in these contexts.

In this research, we chose to explore such context-sensitive innovation through the lens of mountain product value chains (MPVCs), which integrate processes and actors transforming raw materials into marketable goods (Fabre et al 2021). MPVCs are thus at the intersection of land-use practices, traditions, and product valorizations, while dealing with natural constraints and policy frameworks; this makes them an interesting laboratory for observing emerging innovations for the transition. Ostrom's social–ecological systems framework also emphasizes "interactions" as a fundamental component for balancing ecological and social outcomes (Ostrom 2009; McGinnis and Ostrom 2014). We argue that MPVCs exemplify such interactions between actors and resources (Moretti et al 2023). In their economic dimension, value chains connect to national and global markets and can bring in innovation through exchange (Eakin et al 2017; Moretti et al 2023), at any point along the chain—from production and processing to marketing and distribution (Bosworth et al 2020). Innovative value chains can support the transition through improved environmental practices, higher quality products, and new social enterprise models (Gretter et al 2019).

In line with the "inclusive" pillar of the transition, we purposefully adopted a larger lens on the type of innovation considered, considering rural sociology studies that have identified "territorial innovation" as a locally embedded, knowledge-sharing process driven by place-based actors, especially in tourism (Coria and Castro 2020). These forms of innovation, including social innovation, can enhance community wellbeing and closely influence locally embedded MPVCs (Kluvánková et al 2018; Guercini and Cova 2022; Davis and Wagner 2024). This study looked at MPVCs spanning agriculture, tourism, and forestry, aiming to provide an empirically grounded typology. We defined a scope limited to these sectors and excluded, for example, manufacture of other goods, the care economy, and so forth, to focus on MPVCs with high constraints and vulnerability (González-Moreno et al 2025), high policy relevance, and specificities to each mountain territory (Gløersen, Price, et al 2016).

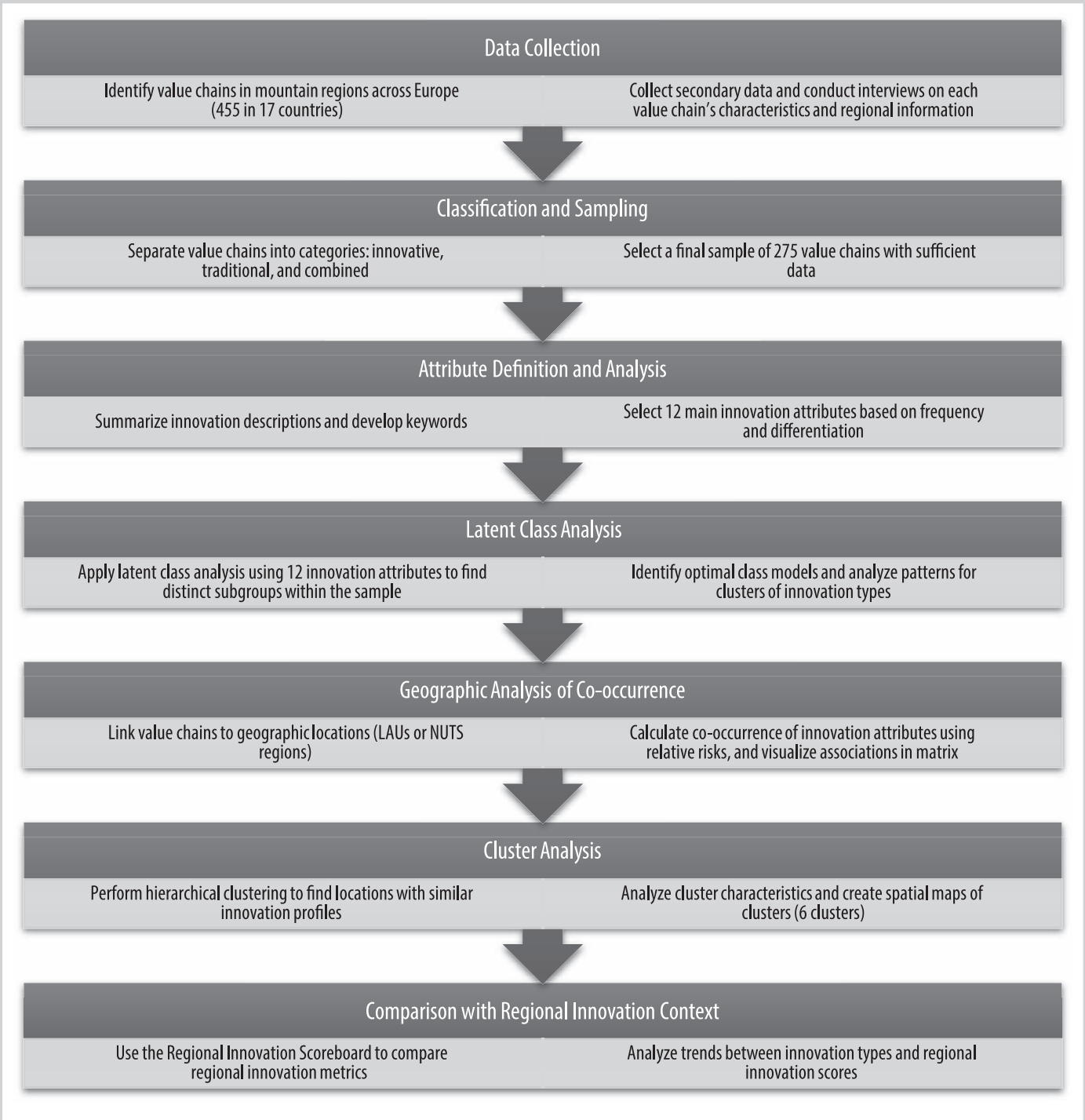
Empirical observation of innovation in MPVCs is a way to describe how the transition is being operationalized, whether green, smart, and/or inclusive, and to provide "policy-relevant evidence" as called for by Gløersen, Mader, and Ruoss (2016). This information can help to inform policies, including the CAP, which provides 6% of its fund (EC 2023b) to support areas with natural constraints (ANCs), including mountains, with the aim of maintaining profitable rural activities. These payments to farmers are now considered part of the European Agricultural Fund for Rural Development's "environmental and climate ring-fencing" (EC 2023b). This fund can be mobilized for RDPs, provided they incorporate predefined measures from a list of 20, which include support for mountain areas at the same level as animal welfare, cooperation, etc (EC n.d.), without indicating how these measures could reinforce or exclude each other. In short, the way in which policy support is effectively targeting and speeding up mountain-specific innovation in MPVCs for the transition remains widely underexplored.

The study analyzed a unique inventory of 455 MPVCs compiled as part of the project "Mountain Valorization through Interconnectedness and Green Growth," offering qualitative data from across Europe's mountain regions.

This study addressed the following research questions:

- What types of innovation emerge from a broad inventory of MPVCs across Europe?
- How do different types of innovation interact, and in what ways do they influence each other?
- What territorial factors act as drivers or barriers to the emergence of these innovations?
- What lessons can be learned to help policies and mountain regions better leverage MPVCs for regional wellbeing and environmental sustainability?

FIGURE 1 Methodological steps applied during this study. LAU, local administrative unit; NUTS, Nomenclature of Territorial Units for Statistics.



Method

The methodology involved data collection by local teams across 455 MPVCs in Europe, using secondary data and short interviews to describe value chains and their innovations. A typology of innovation was developed through text analysis and iterative categorization (see details in Appendix S1, *Supplemental material*, https://doi.org/10.1659/mrd.2024.00042.S1); 12 attributes of innovation were defined. Attributes are keywords that characterize a particular innovation. The selection and definition of the attributes was later confirmed using the Perplexity search engine. Subsequently, several statistical tests were conducted, including latent class analysis (LCA) to identify subgroups of innovations. Geographic co-occurrences of innovation attributes were also explored to understand emerging clusters. Figure 1 summarizes the method in 7 steps; a more developed description, including the details of the R packages and datasets used, is provided in Appendix S1 (*Supplemental material*, https://doi.org/10.1659/mrd.2024.00042.S1).

TABLE 1 Attributes of innovation empirically defined from the inventory of innovative mountain products value chains (n = 275) in descending order of frequency, with the word in italics used for the legends in Figures 1–4. (Table continued on next page.)

Attribute (by frequency)		Key elements found in inventory	Description	Example from dataset
1	*Marketing* (91)	• Joint marketing and sales strategies • Social media campaigns • Branding/image tied to mountain origin • Event/festival sponsorship	Innovative approaches for promoting and selling products, including branding, competitions, and digital outreach to locals and nonlocals	Norway (barley flour and groat): Farmers manage the entire value chain, selling products via e-commerce supported by regional branding
2	Product innovation and re*design* (75)	• Diverse product creation and redesign • New products responding to market/climate shifts	Creation of new or significantly improved products, often through diversification or adaptation to changing market demands	Austria (Almenland herbs): Creation of diverse products such as spice mixes, syrups, and nonfood items, such as soaps
3	Collaborative *governance* (72)	• Democratic decision-making in interprofessions • Sector-linking actors • Integration in cooperative systems • Collective ownership and management	New structures/processes for decision-making and coordination within value chains, often with product certification in interprofessions	Austria (Bio vom Berg Cooperative): Democratic governance among farmers, direct online sales to secure farmer incomes
4	*Ecological* practices (68)	• Sustainable production/resource management • Agroecological practices • Local/regional sourcing, local varieties	Innovative, ecologically balanced practices using local resources and knowledge, promoting biodiversity, preserving nature	Spain (Sierra Morena): Use of local goat breeds, solar energy, and bioremediation for agroecological cheese production
5	*Social* inclusion (65)	• Inclusive actor engagement • Involvement of marginalized groups • Cross-sectoral collaboration	Innovations that foster community involvement, equitable participation, and collaboration	Czechia (herbal tea): Employment of disadvantaged groups in herbal tea production, enhancing social inclusion
6	Research and innovation (*R&I*) (47)	• Collaborations with experts/research • Testing of practices (eg grazing)	Systematic efforts to acquire new knowledge or technology to improve value chain products/processes	Greece (Dikti region): Aloe vera farming using organic practices for products such as juices and cosmetics
7	*Retro*-innovation (46)	• Revival of traditional knowledge, ensuring continuity • Traditional product reintroduction	Reintroduction of historical practices, products, or breeds, combining old techniques with new technology and modern markets	Serbia (Nov Varos buckwheat): Revitalization of buckwheat as a pesticide-free, healthy food
8	Cross-sector *tourism* integration (37)	• Linking of tourism with local products, festivals • Agritourism • Health/wellness integration	Cross-industry partnerships creating synergies, often connecting food production with tourism and local culture	Romania (certified ecotours): Offer of experiences in natural parks, including tours with experienced local guides to visit wolf, lynx, and bear tracks
9	Innovative *processing* (36)	• Local processing techniques and new processing techniques • Vertical integration with processing facilities	New/improved methods of transforming raw products into unique food items, enhancing quality and circularity	Austria (Almenland Stollenkäse): Cheese is aged in a former mine, creating a distinctive product
10	Quality and *certification* (29)	• Quality certification schemes • Sustainability/animal welfare standards	Innovations in certification to ensure product quality, sustainability, and origin	Serbia (Ivanjica potatoes): Protected designation certification adds value for marketing

TABLE 1 Continued. (First part of Table 1 on previous page.)

Attribute (by frequency)		Key elements found in inventory	Description	Example from dataset
11	Innovative *distribution* channels (27)	• Online and direct sales in response to demand • Short supply chains, farmers' markets	Innovative distribution methods, including direct and online sales, and partnerships with retailers	Hungary (Bakony honey): Traditional honey is marketed with innovative packaging and short supply chain sales online
12	Adaptive *production* techniques (27)	• Diversified mountain production (eg fish farming, varieties) • New/retro husbandry methods	Improved methods for crop/animal production, focusing on quality, efficiency, and market adaptation	Austria (fish farming): Nontraditional fish farming to meet demand for domestic freshwater fish

Results

Attributes of innovation

In the inventory (Moretti et al 2021), 275 descriptions were retained as including innovative aspects, but only 56 value chains (20% of the sample) were classified solely as "innovative," and all others also included traditional practices. Table 1 presents the 12 attributes of innovation that iteratively emerged, in descending order of frequency, providing a definition and an example for each. The attributes' names are hereafter written in italics. Altogether, these attributes appeared 620 times across the sample, averaging 2.3 attributes per value chain.

Marketing emerged in one third of all descriptions and encompassed a range of practices, from the use of social media and online stores to promotional events, fairs, and competitions. Additionally, branding played a central role here, with MPVCs often promoting regional or mountain-specific qualities.

The next 4 most frequent attributes—*product innovation and redesign*, *collaborative governance*, *ecological practices*, and *social inclusion*—each appeared in 23–27% of the 275 MPVCs. *Product innovation and redesign* includes the creation of new products or their adaptation to meet changing market demands or climate conditions. *Collaborative governance* reflects efforts to introduce democratic decision-making, cooperative ownership models, or cross-sector alliances. *Ecological practices* emphasize resource management and the incorporation of locally adapted agroecological methods, promoting both environmental stewardship and local biodiversity. Finally, *social inclusion* captures the involvement of diverse actors, especially disadvantaged or marginalized groups, fostering equitable engagement in the value chain.

FIGURE 2 Latent class analysis of the attributes of innovation in the inventory, showing results in 6 classes.

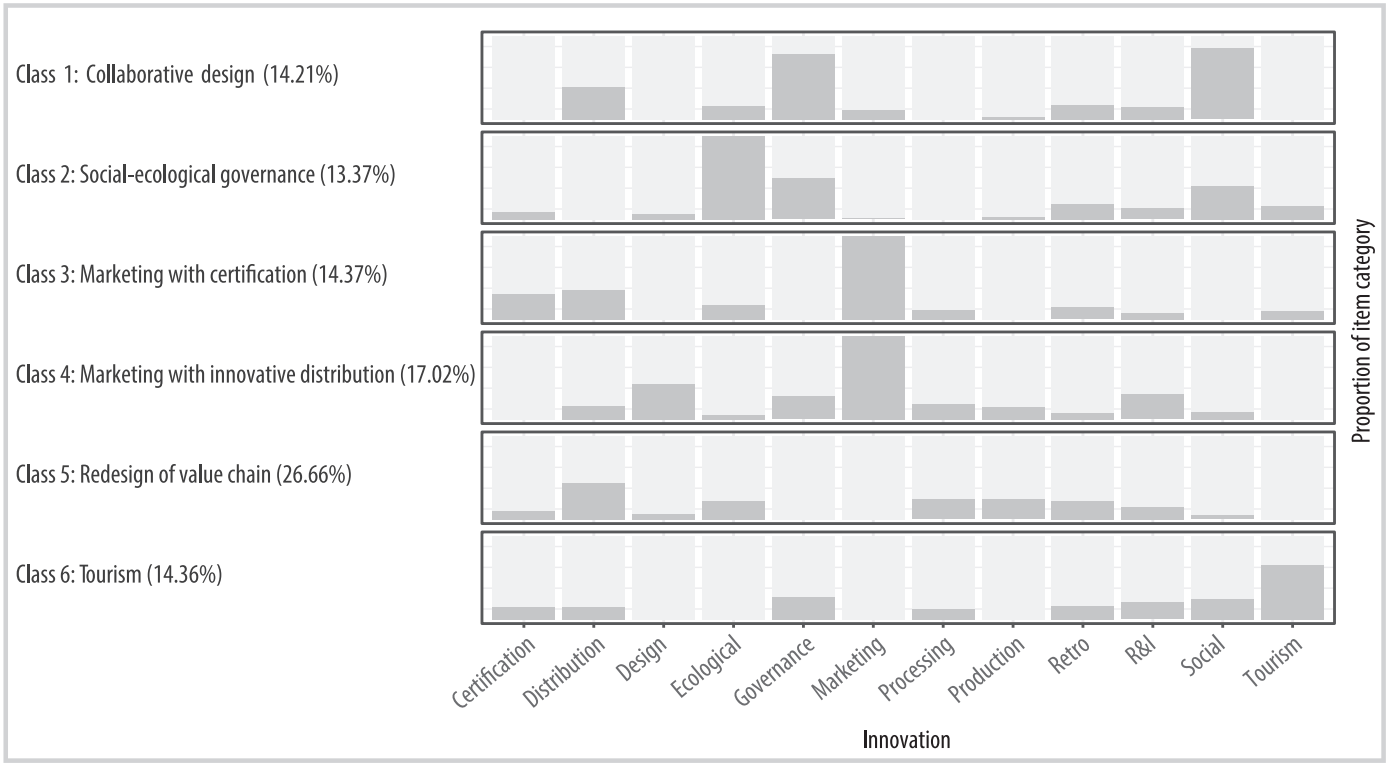
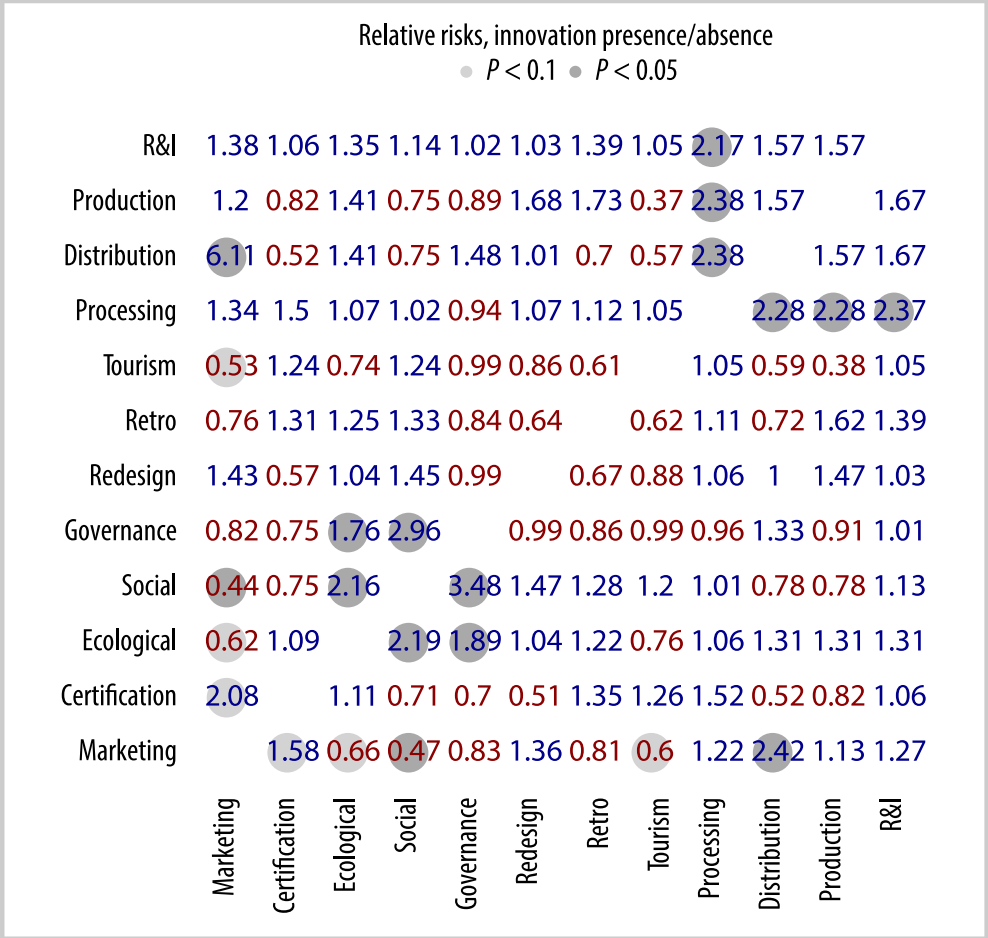


FIGURE 3 Pairwise associations between attributes of innovation for MPVCs across Europe, showing relative risks (numerical values) and statistically significant associations (shaded background). Relative risks show how many times more likely the innovation on the vertical (*y*) axis is, if the innovation on the horizontal (*x*) axis is also present in the same location, where values below 1 show a reduction in the likelihood.



The remaining 7 attributes—including *research and innovation (R&I)*, *retro-innovation* (a term defined by Zagata et al [2020]), and *cross-sector tourism integration*—appeared in 9–17% of cases. The least frequent 4 attributes, *innovative processing*, *quality and certification*, *innovative distribution channels*, and *adaptive production techniques*, are tied to particular stages within the value chain. *Innovative processing*, for example, frequently focuses on new techniques that enhance product quality, shelf-life, or distinctiveness. The attribute of *quality and certification* establishes standards for quality, sustainability, or origin, thereby adding credibility and value to the products. *Innovative distribution channels* and *adaptive production techniques* address logistic aspects, from shortening supply chains to diversifying production, demonstrating how innovation could enhance each stage.

Clustering of innovation attributes

The clustering analyses and quantitative tests indicated that groups of MPVCs with similar innovation attribute patterns could be inferred from probabilistic patterns in the data. The LCA showed better clustering with 2 and with 4–6 classes (Table S1 in Appendix S2, *Supplemental material*, https://doi.org/10.1659/mrd.2024.00042.S1). The proportions of each attribute by class were graphed. Figure 2 shows the results for the model with 6 classes; the graphs for the other models are shown in Figure S1 (Appendix S2, *Supplemental material*, https://doi.org/10.1659/mrd.2024.00042.S1). Classes were not necessarily formed with the thematically closest attributes.

With few classes (2 or 3), a first subgroup can be seen around the attributes of *collaborative governance*, *social inclusion*, and *ecological practices*, and a second one can be seen clearly grouping *marketing* and *product innovation and redesign*. The attributes *processing*, *production*, *certification*, and *distribution* are more often together with the second group, while *tourism* is higher in the first group. These 2 subgroups remained when the inventory was divided into 5 or 6 classes, along with additional subgroups that were given tentative names (Figure 2).

Further tests identified whether the presence of 1 attribute elevated the probability of finding another one in the same location (Figure 3). We observed that *ecological*, *social*, and *governance* innovations were likely to co-occur. For example, *social inclusion* was 3.48 times more likely to occur if *collaborative governance* was also present; this represents a moderate positive effect after Ferguson (2009). *Ecological practices* were 2.2 times and 1.9 times more likely to be present when *social inclusion* and *collaborative governance*, respectively, were present.

TABLE 2 The percentage of regions across the 2 and 6 cluster typologies where different forms of innovation were taking place. Percentages are rounded to one decimal place. "Sig" columns indicate when statistical significance was found. Bold script highlights the results corresponding to the LCA subgroups indicated in the last row.

Model	2 cluster			6 cluster						
Cluster	1	2	Sig	1	2	3	4	5	6	Sig
Number of regions	50	132		50	38	47	16	13	18	
Attributes										
Production	0	18.9	*	0	0	14.9	0	0	**100**	*
Tourism	6	24.2	*	6	10.5	25.5	**100**	0	0	*
Redesign	34	31.1		34	10.5	23.4	37.5	**100**	**38.9**	*
Social	68	15.2	*	**68**	5.3	27.7	31.2	0	0	*
Governance	62	24.2	*	**62**	7.9	**57.4**	0	0	11.1	*
Ecological	60	16.7	*	**60**	2.6	36.2	0	0	22.2	*
Marketing	12	50	*	12	**71.1**	44.7	31.2	**53.8**	33.3	*
R&I	8	27.3	*	8	13.2	55.3	6.2	0	22.2	*
Certification	4	18.2	*	4	**47.4**	12.8	0	0	0	*
Processing	0	22.7	*	0	2.6	40.4	18.8	23.1	22.2	*
Retro	16	23.5		16	**28.9**	34	6.2	0	16.7	*
Distribution	2	18.2	*	2	18.4	**25.5**	0	7.7	22.2	*
Similarity with LCA subgroups				Social–ecological governance	Marketing with certification	Marketing with innovative distribution	Tourism	Redesign of value chain	None, or "Redesign of production"	

*Statistically significant association (chi-square test or Fisher's exact test, $P < 0.05$) between cluster typology and innovation type.

Distribution was over 6 times more likely to occur when *marketing* was present. *Marketing* also had a significant positive association with *certification*. However, the likelihood of *tourism*, *social*, and *ecological* innovations being present in a location was significantly reduced if *marketing* was present. There were also statistically significant associations between *processing* and each of the 3 attributes of *distribution*, *production*, and *R&I*.

The multivariate cluster analysis conducted after the pairwise associations identified 2 and 6 cluster classifications to group regions with similar patterns of innovation (Table 2). Cluster 1 contained 50 regions, and it was distinguished by a high frequency of *social*, *governance*, and *ecological* innovations; these were found in 68%, 62%, and 60% of regions, respectively, in cluster 1. Therefore, this cluster appeared to correspond with the LCA class 2 and confirmed the positive bivariate associations between these innovation types. Conversely, only a small number of regions in cluster 1 had evidence of *processing* and *distribution* attributes. In the 6 cluster model, *marketing* was present in 72% and *certification* was present in 47% of the regions in cluster 2. There appears to be an obvious trade-off between the *ecological*, *social*, and *governance* innovations and those in *processing* and *production*. Cluster 3 is harder to interpret, as several forms of innovation were found at a moderate level. However, *R&I* and *governance* innovations were found in over half of the regions in this cluster.

Clusters 4, 5, and 6 showed a more uneven innovation profile and contained fewer regions. Cluster 4 was distinguished by *tourism* innovations (found in all locations), but 5 attributes (*certification*, *ecological*, *governance*, *distribution*, and *production*) were notably absent in this cluster. All locations in cluster 5 showed evidence of *redesign* innovations, and *production* innovations were found throughout cluster 6. All of the 12 attributes significantly differed (at the 95% confidence level) in their distribution across the 6 clusters, and all innovation types except 2 (*redesign* and *retro-innovation*) were significantly associated with the 2 cluster classification. Figure 4 offers a visualization of the data in Table 2, showing the percentage of regions in each cluster where the respective attributes were present. The line reaching the outer edge shows the cluster where the percentage is highest, corresponding with the highest number per attribute in Table 2.

Geographical trends

The repartition of innovation attributes by country hints at geographical trends in the co-occurrence overlapping with the subgroups and clusters identified before. However, the samples of MPVCs per country (Table S2 in Appendix S2, *Supplemental material*, https://doi.org/10.1659/mrd.2024.00042.S1) were not homogeneous, as bigger countries had more MPVCs in the inventory. Spain had notably more attributes, especially *social*, *ecological*, and *governance*, as did France, suggesting the presence of class 2/cluster 1. *Marketing* was the most present and especially dominant in Austria, Hungary, Italy, Serbia, and Scandinavia.

FIGURE 4 Radar plot visualizing the percentages of regions in the 6 clusters where different forms of innovation are taking place (data in Table 2). The scale (outer and inner edges) is normalized to correspond with the highest and lowest percentages for each innovation type. From the data in Table 2, this difference is the highest for *production innovations* and *tourism* (100% in cluster 6 or 4 minus 0% in other clusters). The difference in percentages (ie rows in Table 2) reduces moving clockwise around the chart, with the smallest difference for *distribution* (25.5% in cluster 3 minus 0% in cluster 4).

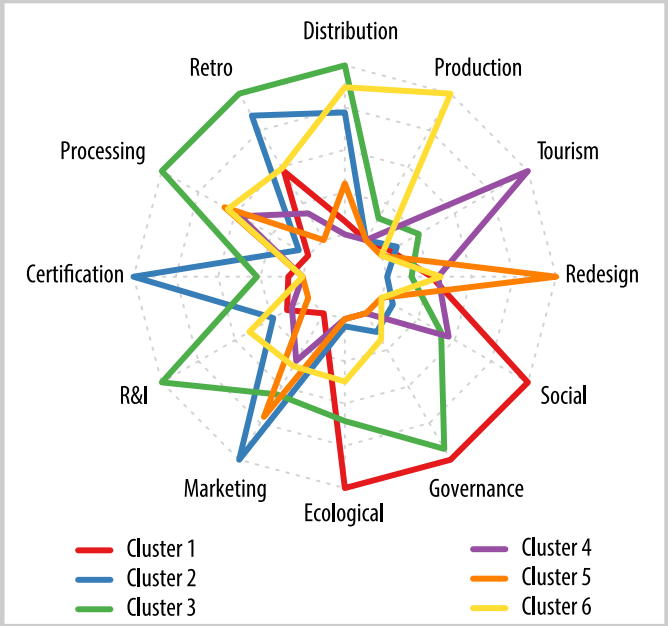


Figure 5 and Figure S2 (Appendix S2, *Supplemental material*, https://doi.org/10.1659/mrd.2024.00042.S1) show maps of the clusters described in Table 2 and Figure 4. It is clearly visible that clusters 4–6 are less dense overall and less present in the west, but no clear relationship of cluster with countries appears.

Finally, the 6 clusters of innovation patterns in regions were cross-tabulated with the RIS results (Table 3). The RIS classified 36 out of 239 European regions, for which innovation performance was greater than 125% of the EU average, as "innovation leaders" (EC 2023a). It is notable that only 5 of the MPVCs were situated in these regions (in Switzerland and Norway). However, Table 3 shows that many innovations are situated in mountain regions that demonstrate below average levels of innovation in the RIS.

Discussion

Our analysis of innovation in 275 MPVCs revealed a new typology of 12 attributes with notable trends in their co-occurrence. Three common denominators emerged: clusters around *social–ecological governance*, around *marketing*, and around *tourism*. Underlying the first cluster is one of the strongest relationships in our sample: *social inclusion* and *collaborative governance*, which are 3 to 4 times more likely to appear together than with other attributes. This reflects the interlinkage of social innovation with new forms of community organization within MPVCs, making the two innovation types challenging to distinguish clearly.

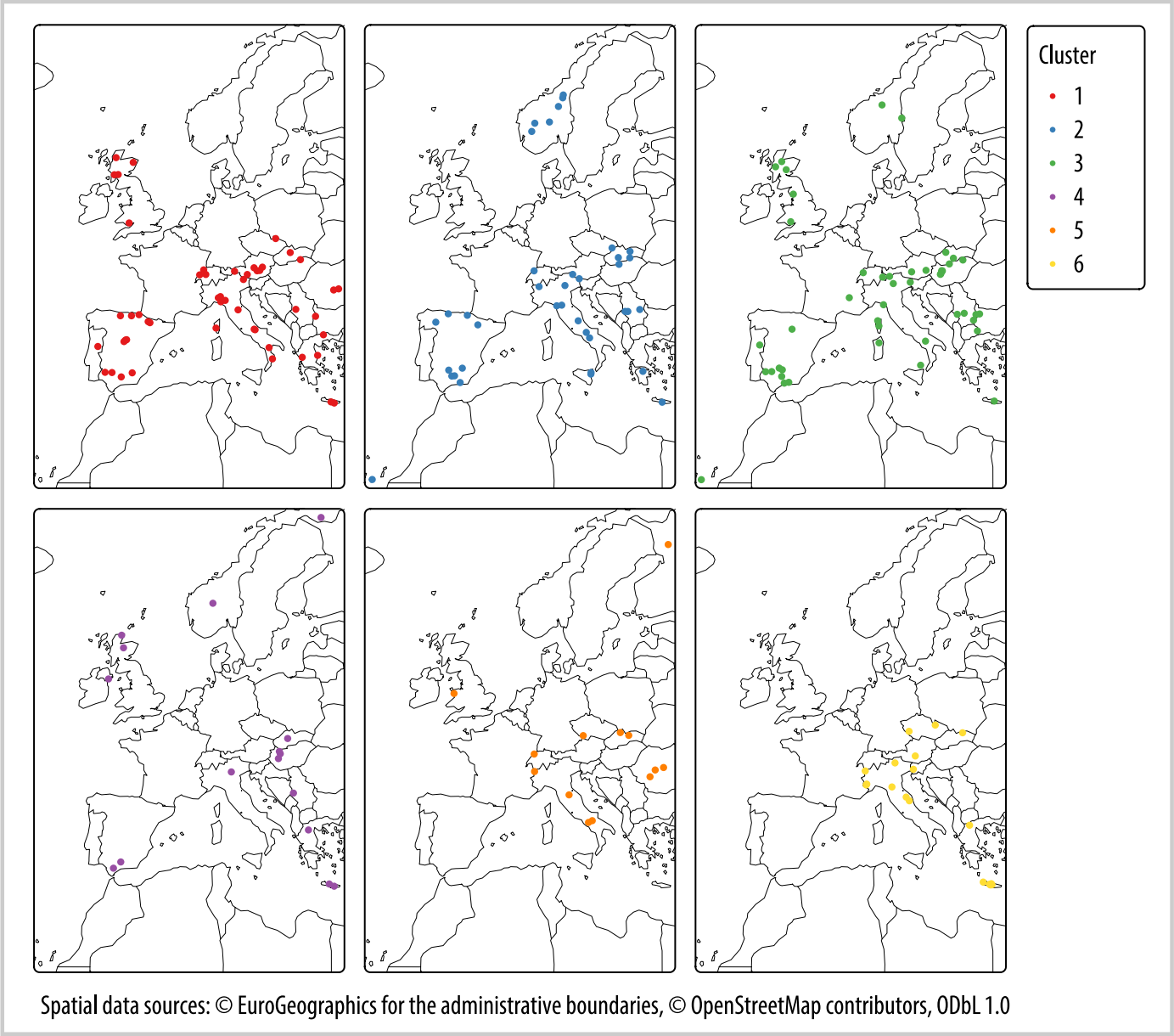
Some researchers consider these types separately (Bock 2016), while others categorize them together (Kluvánková et al 2018; Perlik 2021), suggesting that this combination represents a distinctive style of innovation in rural contexts. Sarkki and colleagues (Sarkki, Ficko, et al 2019; Sarkki, Parpan, et al 2019) and Ravazzoli et al (2021) further maintain that social innovation is critical in driving governance changes. Our study confirms that *social inclusion* and *collaborative governance* not only coexist but, especially in mountain regions, reinforce each other, creating a resilient foundation for collaborative and inclusive rural innovation.

We also found that *ecological practices* were significantly more likely to emerge when *social inclusion* or *collaborative governance* was present. This important finding fully aligns with the increasing recognition of the interconnectedness of, and need for, social cohesion and bottom-up governance to drive ecological sustainability and resilience in mountain areas (Wyss et al 2022). Studies confirm that social–ecological challenges require innovations that reconfigure socioeconomic practices and engage local communities (Melnykovych et al 2018). The synergies among social, governance-oriented, and ecological innovations reflect the interconnected nature of sustainability challenges in these regions and reinforce the need to govern these areas as social–ecological systems. While not implying causation, this trend highlights the finding that ecological innovation is more commonly associated with social and organizational improvements than with other innovation types.

These findings challenge prevailing assumptions embedded in rural policies and innovation indicators, which often emphasize technology, digital transformation, and economic scalability as core criteria. Our study shows that in mountain regions, innovation is not primarily technical but rather socially and ecologically grounded, emerging from community organization, resource stewardship, and governance adaptation. Our evidence supports the idea that innovation in marginal areas is often nonlinear, necessity-driven, and deeply embedded in local contexts. These forms of innovation are no less significant than technological breakthroughs; in fact, they may be more relevant to the complex sustainability challenges and vulnerabilities these regions face (González-Moreno et al 2025). Recognizing this, policy instruments are required that effectively and financially support adaptive, bottom-up, and place-based innovation strategies as legitimate and impactful pathways to development. This includes dedicated support for community organization and social innovation in programs such as LEADER/CLLD and EIP, where strategies and participation are locally defined, with dedicated and increased funds for these programs within ANCs.

Conversely, our finding that *ecological practices* are less likely to occur alongside *marketing* innovation suggests that businesses focused on ecological improvements may forgo marketing strategies and/or that marketing strategies in these regions have yet to integrate sustainability-focused practices. Traditionally, marketing in MPVCs has focused more on messages of regional identity (Martins and Ferreira 2017), such as protected denominations of origin (PDOs) and mountain or regional labels, which are more prevalent in our

FIGURE 5 Spatial distribution of innovation clusters: 6 cluster model.



inventory than organic or high-nature-value farming initiatives. This is reflected in the significant co-occurrence of *marketing* and *certification*. McMorran et al (2015) also found that improvement of food label standards toward environmental requirements is needed especially for MPVCs. *Marketing* remained the most prevalent innovation attribute, frequently focusing on branding, consumer outreach, and identity-building, in line with efforts to increase local added value generation and economic resilience (Martins and Ferreira 2017; Pagliacci et al 2022; Staffolani et al 2022).

Similarly, the limited connections between value-chain-specific innovations and *social* or *ecological* innovations suggest a limited emphasis on social and environmental values, while the focus remains predominantly on efficiency and productivity. Thus, policy instruments for product promotion, such as PDO regulations and optional quality terms for mountain areas, should be progressively combined with sustainability measures or implemented in closer synergy with governance and social innovation support (eg LEADER/CLLD), as this was shown to co-emerge with ecological practices.

Perhaps the most striking finding was the apparent lack of significant technological or digital innovation among the MPVCs. In our comprehensive inventory, digital or technological advancements were mentioned in so few cases that these attributes were not retained. Marescotti et al (2021) also found that the diffusion of information and communications technology (ICT) was still limited among farmers, especially in mountainous areas and for small farms, because of technophobic attitudinal determinants. They concluded that "the poor success of public policies of smart farming may be due to a top-down undifferentiated intervention" (Marescotti et al 2021: Highlights). We

TABLE 3 Cross-tabulation of 180 regions, based on MPVC innovation cluster and regional performance group, defined at the European level.

MPVC innovation cluster	Regional innovation scoreboard (2023): regional performance group			
	Emerging innovator	Moderate innovator	Strong innovator	Innovation leader
1	8	20	21	1
2	10	20	6	2
3	18	14	11	2
4	6	7	3	0
5	5	5	3	0
6	2	13	3	0

confirm the low presence of ICT-based innovation in the whole MPVC segment, and not only in farming. Similarly, topics such as efficiency and greenhouse gas reductions were remarkably absent. This finding stands in contrast to prevailing narratives, which often highlight the transformative potential of digital technologies in rural and agricultural sectors. Even though broadband access has expanded significantly in mountain regions and is emphasized by EU rural strategies (EC 2021), it has not yet translated into "smart" innovation within the MPVCs in our sample. Thus, while digital infrastructure exists, its role in achieving sustainability goals remains uncertain. Whether this is linked to a lack of coordination of initiatives and policy programs (such as RDP) targeting either mountain constraints or digital innovation, and not both together, could not be tested. Future research could compare the data with the national RDPs and ANC fundings of the last decades.

Our findings also question the adequacy of conventional innovation definitions, such as those within the RIS. In line with the analysis of Coca et al (2023), the high prevalence of ecological and social innovations, paired with the relative scarcity of technological innovation, suggests that existing metrics do not fully capture the innovation most relevant to mountain regions. Consequently, these regions may underperform in the RIS despite the presence of substantive, tangible innovations because they differ from innovation as defined after Schumpeter (1934). The geographical mapping of the innovation clusters showed that all clusters are spread across mountain regions, making a new definition of innovation attributes relevant for all European mountain regions, and likely beyond. The distribution of cluster 1 "*social–ecological governance*" luckily indicates that this type of innovation—conducive to the transition—occurs across the board, irrespective of countries' GDP and RIS group.

These findings have significant implications for policymakers and stakeholders in MPVCs. Investing in social and governance innovation is essential to initiate ecological transitions in mountain areas in addition to digital infrastructure. By prioritizing policies that enhance community ties (ie inclusive actor engagement, involvement of marginalized groups, cross-sectoral collaboration) and collaborative governance (ie democratic decision-making in PDO producers' organizations, sector-linking actors, integration in cooperative systems, collective ownership and management), MPVCs may become more resilient and ecologically sound. Long-running EU programs, such as LEADER/CLLD and EIP, address these needs and seem well tailored but were noticeably absent from the innovation descriptions in the inventory, and their effective contribution to community-led innovation remains unclear, despite showing potential (Nordberg et al 2020). Furthermore, the objectives and RDP measures in the CAP need to both provide dedicated funds for mountain areas and tie these funds to social and governance innovation support as levers for ecological practices. Indeed, Iammarino et al (2019) also suggested that policies for long-term innovation and productivity growth need to be based on hedging bets by promoting broad-based capacities for social, institutional, and business innovation.

The generalizability of our findings may, however, be affected by limitations, such as in the data collection process, which faced challenges in terms of consistency across different regions and countries. The clustering methods tested were complex, but their redundancy allowed some cross-confirmation of findings. While the study highlights innovation across a diverse set of MPVCs, it is important to acknowledge the structural limitations inherent in the dominant sectors—particularly food production and tourism. These sectors, which account for a large share of MPVCs, are often characterized by low added value, seasonal dynamics, and dependence on external markets and consumer demand. Moreover, the ecological impact of expanding consumer-oriented sectors—for instance, through overtourism or land-use intensification—can lead to resource strain or homogenization of local economies. This reinforces the importance of supporting innovation strategies that not only enhance resilience within these sectors, but also diversify the economic base of mountain communities, as was proposed in Sega and Perlik (2022). Encouraging cross-sectoral synergies, value-added processing, or knowledge-based services could help to mitigate the risks of overdependence on a core sector and on public support.

In conclusion, our study provides valuable insights into innovation patterns in European MPVCs, but it also raises new questions for further research. The importance of social and governance innovations in driving ecological practices and the relative absence of technological

innovations suggest a need for a more coordinated and context-specific approach to innovation policies in mountain regions. Future studies could benefit from a more in-depth exploration of the barriers and enablers of different types of innovation in these unique social–ecological systems, perhaps utilizing the new typology of 12 attributes to frame innovation and approaches such as Living Labs to capture the full spectrum of innovation occurring in mountain areas. By recognizing and supporting the types of innovations that are actually occurring, policymakers can more effectively foster sustainable development in these vital and often vulnerable areas.

USE OF GENERATIVE ARTIFICIAL INTELLIGENCE

When preparing this work, the author(s) used Perplexity.ai and ChatGPT.ai in order to proof their categorization of descriptive information, after doing it manually. These tools were also used to synthesize text, improve formulation, and understand literature. After using these tools, the authors carefully reviewed and edited the content as needed. The authors take full responsibility for the content of this article.

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Supplemental material

APPENDIX S1 Detailed method.
APPENDIX S2 Supplementary results and figures.

Found at: https://doi.org/10.1659/mrd.2024.00042.S1